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Title: Overview of Charm Producton - J/psi and Open Charm (U)

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Overview of Charm Production – J/ψ's and Open Charm

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Abstract. Heavy quark production provides a sensitive window for the study of the gluon structure of nucleons and its modification in nuclei. It also provides a very important means of studying the hot-dense conditions created in high-energy collisions of heavy nuclei and a critical probe to look for deconfinement in this hot-dense matter. I will review, from an experimental point of view, the physics issues as seen in current experimental results for charm production and point out the remaining puzzles.

Keywords: Heavy quarks, J/ψ, ψ' and ϒ, nuclear effects, shadowing.
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J/ψ, ψ' and ϒ's are produced primarily from gluons in the projectile and target. Open charm or beauty production shares this sensitivity to the gluons as well as to other initial state effects in nuclei such as initial-state gluon energy loss and multiple scattering causing p_T broadening. However, only the bound heavy-quark states suffer absorption in the final state. A longstanding problem in J/ψ production is that models that produced singlet $c\bar{c}$ state predicted cross sections that were several orders of magnitude smaller than those observed in CDF[1]. Although color-octet production (COM) is able to reproduce these cross sections the matrix elements determined are not universal and don't work for photo production of J/ψ's. A serious problem is that the COM predicts transverse polarization at high p_T, but all measurements (CDF, E866/NuSea[2]) so far see no substantial polarization. One exception to this is in the ϒ sector, where the Υ_{1S}, like the J/ψ, has no polarization whereas the Υ_{2S+3S} has maximal polarization[3]. It is possible this is because the higher ϒ states have little feed-down from higher mass states, while both the J/ψ and Υ_{1S} have substantial feed-down (~30% for the J/ψ[4]) which tends to destroy any polarization. Clearly a measurement of the ψ' polarization would be of interest since it does not suffer from feed-down. For single charm (D meson) production, recent results from RHIC at $\sqrt{S}$ = 200 GeV are presently confused by a factor of two (but only 3-sigma) disagreement between results from STAR and PHENIX[5].

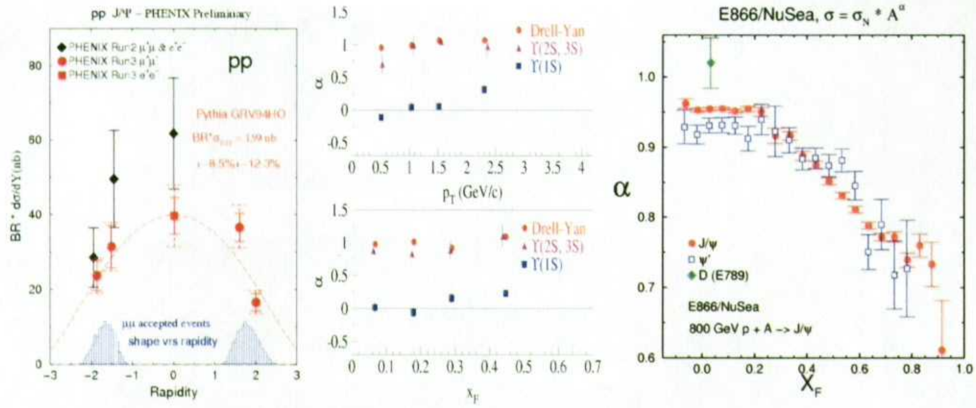

FIGURE 1. a) First measurements of the J/ψ cross section for √s = 200 GeV pp collisions from PHENIX. b) Polarization of Υ production at 800 GeV showing none for the Υ_{1S} and maximal for the Υ_{2S+3S}. c) Nuclear dependence versus x_F for J/ψ and ψ' production at 800 GeV.

Effects of the nuclear medium on production of heavy quarks include shadowing (depletion at small x) of the gluon distributions in a nucleus, energy loss and multiple scattering of the gluons before the hard interaction, and, for onia, final-state absorption. Shadowing is thought to involved coherence effects that effectively "shadow" the partons inside a nucleus or can also be thought of as a saturation effect in a nucleus, where at small enough x the gluons from different nucleons overlap and interact with each other – causing a promotion through gg→g interactions to higher x and a corresponding reduction in their populations at small x, e.g. as in a recent model called the color-glass condensate (CGC)[6].

The E866 nuclear dependence versus x_F is shown in Fig. 1c, where α=1 would correspond to no change in the per nucleon cross section. Near $x_F = 0$ the suppression of the resonances and lack of suppression of open-charm is thought to be due to absorption of the resonances. At these small x_F values the $c\bar{c}$'s are moving slowly out of the nucleus after their creation should be starting to hadronize in the nucleus and the larger suppression of the ψ' relative to the J/ψ would be due to the larger size and looser binding of the ψ' compared to the J/ψ. While at larger x_F they traverse the nucleus as a $c\bar{c}$ pair, only hadronizing way outside, and therefore experience the same effects. The strong increase of the suppression as x_F increases is thought to be due to a combination of shadowing (large x_F is small x in the nuclear target) and also energy loss of the gluon in the initial state[7]. As shown in Fig. 2b, new data from PHENIX at √s = 200 GeV also shows similar features, but so far with much worse statistical precision. However, if one looks at the suppression seen at three different energies (√s = 19 GeV (NA3), 39 GeV (E866) and 200 GeV (PHENIX)) the suppression does not scale with x_2 but does, as shown in Fig. 2c, with x_F. This appears to indicate that shadowing (which should scale with x_2), is not the dominant physics in the large x_F behavior of the J/ψ. The reason for the apparent scaling with x_F remains a puzzle, although I suppose it conceivable that energy loss provides the bulk of the high-x_F suppression at the lower energies but that it vanishes at higher energies (RHIC) where only a weak shadowing is seen. Early studies at RHIC also indicate, that open-charm is not modified in either d-Au or Au-Au collisions.

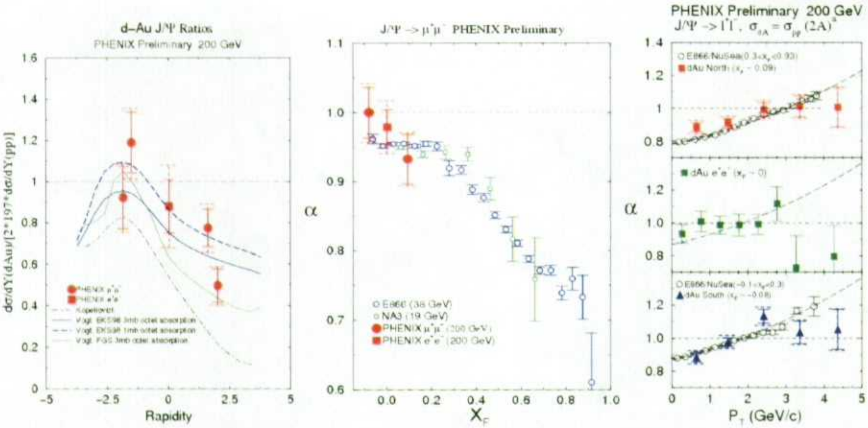

FIGURE 2. a) Nuclear dependence of J/ψ production versus rapidity at √s = 200 GeV. b) Same versus x_F. c) p_T broadening for J/ψ production at √s = 39 GeV.

In Fig. 2c, one also sees that J/ψ production experiences p_T broadening, generally thought to come from multiple-scattering in the initial state.

In high-energy nucleus-nucleus collisions heavy quarks and the onia are thought to provide an important tool for the detection and study of the strongly interacting deconfined matter that may be made. In particular the color-screening in a deconfined media would heavily suppress J/ψ production[8]. On the other hand, recent models driven by the large amount of charm created in these collisions also predict an enhancement from recombination of that charm[9]. At CERN when the observed suppression in Pb-Pb collisions was compared to simple estimates using a fixed nuclear cross section for the normal suppression (as determined from p-nucleus studies)[10]; an anomalous suppression at high energy density (small impact parameter collisions) was observed and, by some, is cited as evidence of creation of a quark-gluon plasma. However, to many the estimate of the normal nuclear suppression seems inadequate to clearly determine if the new de-confined state of matter was actually seen. So far similar studies for the higher-energy collisions at RHIC have been inconclusive due the to low luminosity at RHIC so far and the corresponding low statistics for J/ψ in Au-Au collisions[11]. We are looking forward to more substantial results in the near future as the analysis is completed of the much higher RHIC Au-Au run just completed.

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